Parametric Sub-Bottom Profiler For AUVs

Deep-Penetration, High-Spatial-Resolution Sub-Bottom Imagery In a Compact, Low-Power Form Factor

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SAMS deployment with PFRS installed.

Autonomous underwater vehicles (AUV) are fast becoming viable survey platforms. With this growth, new survey tools have emerged. The Naval Oceanographic Office's (NAVOCEANO) profiler for the Subsurface Autonomous Mapping System (SAMS) AUV (PFRS) was developed by Omni Technologies Inc. (OTI) to provide high-resolution, sub-bottom imagery (data).

AUVs have stringent requirements in electrical power budget, size and weight requiring survey sensors that are smaller, lighter, autonomous and more energy efficient than typical survey tools. However, AUVs are excellent survey platforms due to their stability and ability to operate close to the target.

Sub-bottom profilers are used by surveyors to obtain information on surficial marine sediments in cable route surveys, for pipeline route surveys, piling installations, pipeline burial and scour surveys, salvaging operations or any operation where knowledge of bottom and sub-bottom sediments is critical.

Coring is one way of obtaining similar information, but is slow, expensive and provides only minimal coverage. Since marine sediments are incredibly diverse, inhomogeneous and continually in flux, sub-bottom profiling supplemented with strategic coring provides a more complete understanding of the seafloor. Acquiring side scan imagery simultaneously with sub-bottom profiler data provides an optimal mix of coverage, cost and accuracy.

There are numerous sub-bottom profiler configurations with variations

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUL 2006**	2. REPORT TYPE	3. DATES COVERED **00-07-2006 to 00-07-2006**
4. TITLE AND SUBTITLE **Parametric Sub-Bottom Profiler for AUVs**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Undersea Warfare Center,Newport,RI,02841**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

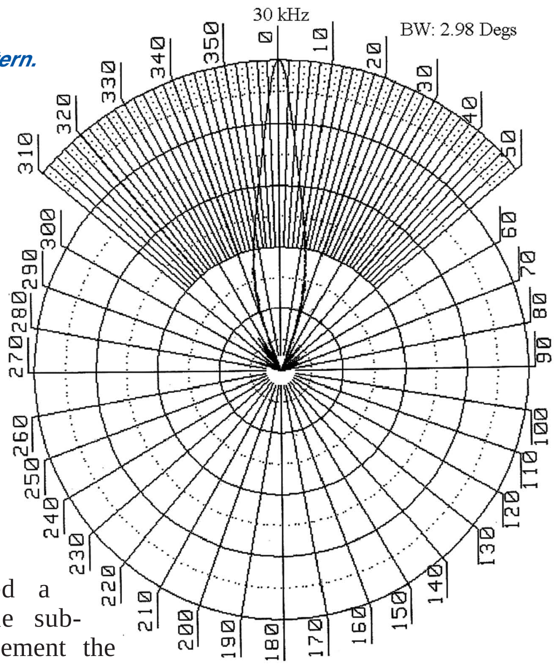
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

in operational frequency, bandwidth, beam width and processing methods. In general, lower frequency profilers operate in the 500 hertz to five kilohertz range and high-frequency systems in the five kilohertz to as high as 100 kilohertz range. Low-frequency systems provide better sediment penetration depths but sacrifice resolution due to the lower bandwidths involved. Higher frequency systems provide

(Right) Parametric beam pattern.



(Left) PFRS at the calibration tank.

better resolution at the expense of penetration depths. Wider beam width systems provide larger coverage areas at the expense of resolution and accuracy. All systems have unique processing methods to improve range, increase resolution, penetrate further, better detect layers and improve sediment classification. The PFRS sub-bottom profiler falls into the high-frequency, wide bandwidth and narrow beam width categories, providing exceptional resolution with reasonable penetration.

SAMS AUV

SAMS is the U.S. Navy's full-ocean-depth capable oceanographic survey AUV designed for two survey missions: independent physical oceanographic data surveys and side scan/sub-bottom mapping surveys. The vehicle weighs approximately 862 kilograms in air, is 4.1 meters long and 0.61 meters in diameter at its widest diameter.

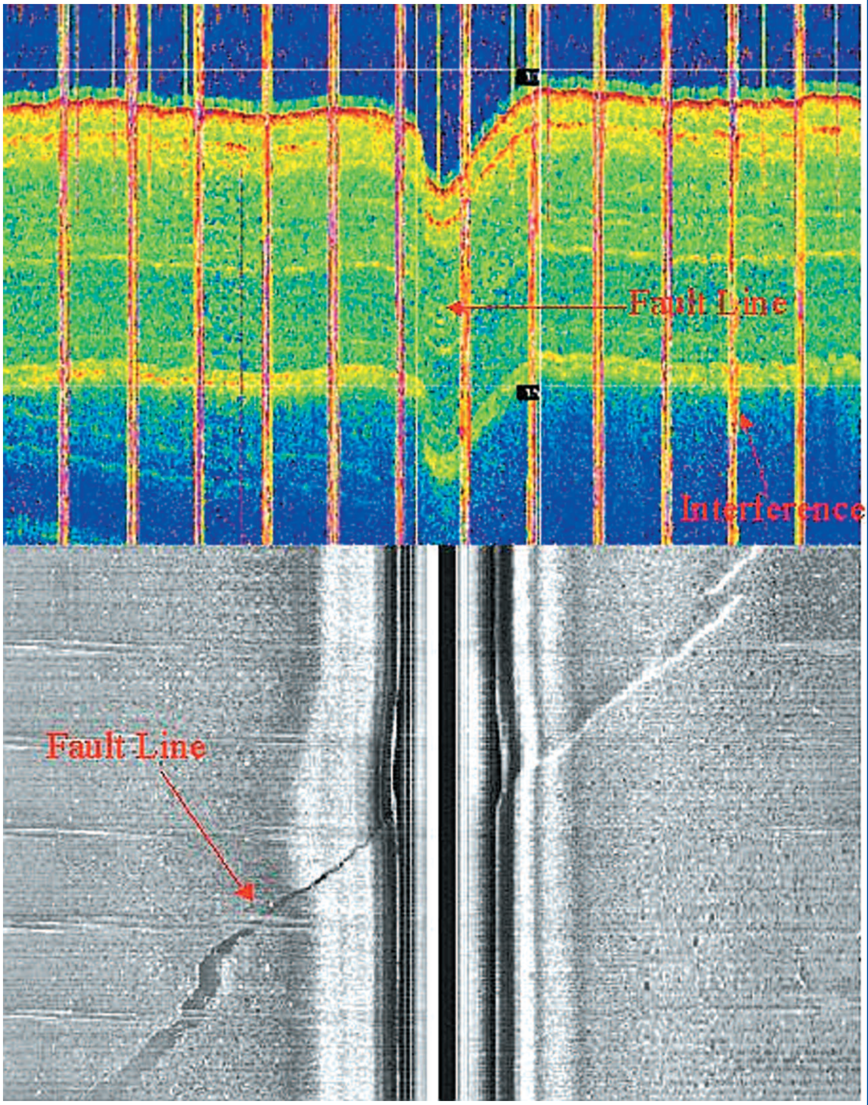
Power is supplied from an eight-kilowatt-hour battery at a nominal 25 volts. The vehicle is free-swimming, primarily utilizing longbase-line and inertial navigation methods. Surveys are programmed prior to deployment, but the vehicle is capable of being redirected mid-survey via acoustic communications. Mission survey endurance is on the order of 12 hours depending on the mission configuration.[1]

Parametric Sonar

NAVOCEANO required a small, deep-ocean-capable sub-bottom profiler to complement the sensor suite on their SAMS AUV. OTI delivered a high-frequency, parametric sub-bottom profiler that optimized resolution and accuracy, as well as provided good penetration. Parametric sonars use the non-linear property of acoustic wave travel in water (sound speed varies as a function of pressure) to mix higher frequency primary acoustic signals (generally two frequencies) to achieve sum and difference frequency components. The difference frequency component in most cases is the frequency of interest. The advantage of this phenomenon is that the low-frequency acoustic energy is generated in the narrow beam of the high-frequency primaries. The beam width of a piston transducer is dictated by the wavelength of the source signal and the diameter of the transducer. Given a fixed diameter transducer, as the frequency increases the beam width decreases. Since a parametric transducer transmits at high primary frequencies where the beam width is narrow, the low difference frequency component that evolves during acoustic propagation in the water has a beam pattern similar to the beam pattern of the primary frequencies. Thus, a small transducer is capable of generating narrow beam, low-frequency signals providing reasonable bottom penetration with excellent spatial resolution. The small transducer is ideal for AUVs due to the limited space and weight capacities of the vehicle.

In addition, parametric sonars offer other advantages. Bandwidth is directly proportional to range resolution. In general, acoustic sources have operational bandwidths of approximately one to two octaves. If a low-frequency source is used, bandwidth is limited since one octave (doubling in frequency) at low frequency has much lower bandwidth than an octave at higher frequencies. For example, a typical low-frequency linear transducer might operate from 20 kilohertz to 30 kilohertz (one octave) providing a bandwidth of 10 kilohertz. A parametric source operating at 200 kilohertz, however, might provide bandwidths on the order of 100 kilohertz. There are some limitations in generating difference frequencies parametrically, and one can expect to obtain difference frequency bandwidths on the order of 50 to 60 kilohertz. These bandwidths are relatively phase and amplitude-flat, providing advantages in signal processing.

The beam width of a parametric sonar remains nearly constant over the operational bandwidth. Thus, target illumination is constant across bandwidth. The beam width of a transducer varies as a function of the ratio of the transducer aperture to the acoustic wavelength within the operating bandwidth. For a fixed transducer aperture and bandwidth, the beam width variation is larger in a low-frequency band than in a high-frequency band. As an example, the beam width of a 12.7-centimeter-diameter transducer operating over a 10-kilohertz bandwidth from a 20-kilohertz to 30-kilohertz range has a beam width variation from 32° to 24° (using a three-decibel beam width criteria). This is an 8° beam width change. The same transducer



Sub-bottom and side scan imagery of a fault line.

operating over a 10-kilohertz bandwidth from 200-kilohertz to 210-kilohertz has a beam width variation from approximately 3.5° to 3.4°. This is a more desirable 0.1° change. When the change in acoustic footprint on the bottom is calculated, the effect is dramatic.

At a 20-meter range, the footprint change in the 20-kilohertz to 30-kilohertz case is approximately 3.1 meters, and in the 200-kilohertz to 210-kilohertz case is only 0.06 meters. Thus, when a linear, wide-bandwidth sonar is used, the target illumination varies with frequency. This creates anomalies in sub-bottom imagery, especially in complex seafloors. The parametric system illuminates the same sediment volume over wide bandwidth, eliminating this effect.

A third advantage of parametric sonar is low Q at the difference frequency. The Q of a transducer is the ratio of the bandwidth divided by the center frequency and is a measure of how resonant a transducer behaves at a particular frequency. A high Q causes pulse ringing or pulse elongation, thus, reducing bandwidth. If a low-frequency and high-frequency transducer have the same bandwidth, the Q of the high-frequency transducer is much lower than the low-frequency transducer because the center frequency in the denominator is larger for the high-frequency transducer. This translates to more bandwidth (better resolution) in many cases since high-Q transducers "ring."

Of course, in physics there are no free lunches and the parametric effect has the disadvantage of poor efficiency and poor short-range performance. The generated source power level at the difference frequency is on the order of one percent of that generated at the primary frequencies. A parametric sonar also requires a reasonable distance before the difference frequency is fully formed, limiting how close the sonar can effectively operate.

PFRS Description

OTI's parametric and linear sub-bottom profiler development efforts began with the Naval Research Laboratory (NRL) in 1996. The PFRS is the latest innovation in this effort. PFRS has proven to be an extremely capable sub-bottom profiler providing exceptional imagery in the smallest, lowest power package known by the authors of this article.

The PFRS system was designed as an integrated package (combined transducer and pressure housing) to minimize failure points, reduce volume and weight, and simplify installation. On the SAMS AUV, the PFRS and camera system are interchangeable units. The units are similar in size and weight, eliminating complicated ballasting requirements. Both units also share a common platform electrical interface, alleviating cabling issues. The camera and PFRS can be interchanged on SAMS in less than 30 minutes.

The PFRS system is 43 centimeters in length and 17.8 centimeters in diameter, weighing 20 kilograms in air. The housing is fabricated from grade A titanium and can withstand pressures of 10,000 pounds per square inch.

The electrical interface to the PFRS system consists of 100BaseT Ethernet, a 24-volt DC nominal (18-volt DC to 36-volt DC) supply voltage, a two-wire flood sensor interface and a trigger input. The entire system operates on an average power of just under 40 watts.

PFRS is configured with a Windows-based program and can also be controlled/monitored via the SAMS control/status program. The embedded hard disk is shared providing easy data access with standard file management methods. Once off-loaded to a mass storage device, data is reviewed using the PFRS playback software.

Parametric Transducer

The PFRS transducer is a piston transducer 17.8 centimeters in diameter and 8.9 centimeters thick. The transducer is rated to an operational pressure of 10,000 pounds per square inch and offers two operational modes: a 200-kilohertz parametric mode and a 30-kilohertz linear mode.

The parametric mode is the normal operating mode providing bandwidth from 10 kilohertz to 60 kilohertz with a constant beam width of approximately 3°. The 30-kilohertz linear mode provides an 18° beam width providing a larger bottom footprint that aides sediment classification processing.

The active material in the PFRS transducer is injection molded 1-3 piezoceramic polymer composite material from Materials Systems Inc. The 1-3 composite material offers the advantage of low Q, wide bandwidth and minimal lateral mode resonances that can produce non-uniform response characteristics and side lobes. Using this material in a parametric transducer provides textbook beam pattern curves with extremely low side lobes.

Results

During a recent SAMS survey, sub-bottom data was collected in conjunction with side scan data. A fault line was discovered during this survey that demonstrates the PFRS system's capabilities.

PFRS was operating at a 10-meter range with a 35-kilohertz difference frequency and obtained bottom penetrations between five and 10 meters in silty clay sediments. Acoustic interference from an acoustic modem is observed in the imagery and remains an item of concern.

Conclusions

The PFRS sub-bottom profiler is an exceptionally-high-resolution and accurate sub-bottom profiler requiring minimal space and power. Parametric acoustics is the enabling technology. By careful design, the efficiency limitations of parametric acoustics can be overcome providing an ideal match for AUVs. Future plans are to transition this technology to man portable AUVs for use in shallow-water surveys.

Acknowledgements

The NAVOCEANO, Stennis Space Center Code N9, provided funding for the development of the PFRS. Special thanks goes to Andrew MacNaughton and Michael Bendzlowicz at NAVOCEANO for their contributions to this article and their support. Funding for early development efforts was provided from the NRL and Office of Naval Research. The authors would like to thank Kenneth Sharp, Rick Swanson, Randy White, Joseph Sparcella, Dan McGovern and Martin Ammond at NAVOCEANO for their support. Doug Lambert, Dale Bibee and Don Walters of the NRL have been innovators pressing forward with research to further the science.

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References

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